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Preliminary Nuclear Criticality Safety Evaluation for the Container Surveillance and Storage Capability (CSSC) Project

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1.0 Introduction

Washington Safety Management Solutions (WSMS) provides criticality safety services to Washington Savannah River Company (WSRC) at the Savannah River Site. One activity at SRS is the Container Surveillance and Storage Capability (CSSC) Project, which will perform surveillances on 3013 containers (hereafter referred to as 3013s) to verify that they meet the Department of Energy (DOE) Standard (STD) 3013¹ for plutonium storage. The project will handle quantities of material that are greater than ANS/ANSI-8.1² single parameter mass limits, and thus required a Nuclear Criticality Safety Evaluation (NCSE).

The WSMS methodology for conducting an NCSE is outlined in the WSMS methods manual³. The WSMS methods manual currently follows the requirements of DOE-O-420.1B⁴, DOE-STD-3007-2007⁵, and the Washington Savannah River Company (WSRC) SCD-3⁶ manual. DOE-STD-3007-2007 describes how a NCSE should be performed, while DOE-O-420.1B outlines the requirements for a Criticality Safety Program (CSP). The WSRC SCD-3 manual implements DOE requirements and ANS standards. NCSEs do not address the Nuclear Criticality Safety (NCS) of non-reactor nuclear facilities that may be affected by overt or covert activities of sabotage, espionage, terrorism or other security malevolence. Events which are beyond the Design Basis Accidents (DBAs) are outside the scope of a double contingency analysis.

2.0 System and Process Description

The CSSC Project will perform surveillances on 3013 containers to verify that they meet the DOE-STD-3013 for plutonium storage. This surveillance will include Non-Destructive Analyses (NDAs) and some destructive analyses.

2.1 Non-Destructive Assay Room

The NDA Room contains two NDA instruments (a Neutron Multiplicity Counter [NMC] and a calorimeter). The NMC will be used to assay both product in 3013s and waste in five-gallon pails. When the 3013 NMC cavity insert is in place, only one 3013 will fit in the NMC. When configured to assay waste, multiple 3013s could fit in the NMC. The calorimeter will assay only product in 3013s or standards and only one item will fit in the cavity. The calorimeter is air cooled and there are no significant sources of liquid moderators in the room or sources of significant moderator that could enter the room from outside.

2.2 Packaging Area

The Packaging Area will have a number of fixed pieces of equipment (qualified positions) that may contain plutonium product cans. These include: a shipping package unpacking station, a leak check station, a scale, a smear counter to check for contamination, an outer can welder, an outer can bell jar skid, a gamma assay unit, and a Digital Radiography (DR) station. [Other “qualified positions” may be designated with concurrence from Criticality Safety Engineering (CSE).] These stations will be fixed and spaced so that there is insignificant neutron interaction between stations if each of the stations contained product containers with fissile material. There will also be fixed isolated positions to store five-gallon waste pails until they can be assayed. A waste pail (after being assayed) will either be returned to the storage rack or be placed in a 55-gallon drum for removal from the CSSC. The storage of multiple 55-gallon drums of Transuranic (TRU) waste in the CSSC Project area is not allowed.

2.3 Glovebox

The glovebox will have dry air (-25 °C dew point specified) and have minimal sources of liquid moderator. The glovebox will contain equipment for puncturing and cutting containers, a scale, a grinder for plutonium oxide, a sieve for size classification, a furnace pan, a furnace to oxidize metal and/or stabilize oxide, and an Inner Can Welder (ICW) to be able to place the stabilized product in a container and remove it from the glovebox without using plastic bags. Samples will be taken of the fissile material and all containers sent to Savannah River National Laboratory (SRNL) for analysis.

2.4 Storage Room

The Storage Room contains approximately 2,000 positions to store qualified 3013 containers and a limited number of annual calibration standards.

2.5 Ventilation System

The ventilation system provides exhaust for the glovebox and process rooms. The ventilation ductwork that comes from the glovebox and process rooms would be expected to contain only contamination levels of plutonium. The gloveboxes have testable High Efficiency Particulate Air (HEPA) filters to prevent significant fissile material from entering the ductwork. It would be an upset for uncontained fissile material beyond contamination levels to be present in the process rooms.

3.0 Approach

The NCSE, also referred to as a Double Contingency Analysis (DCA), evaluates the CSSC to determine if there are any credible scenarios for a criticality accident. DOE-STD-3007-2007 and the WSMS methods manual set forth guidelines on the structure and contents of an NCSE. The objectives of the double contingency analysis included in the NCSE are to:

- Demonstrate compliance of facility operations/processes with the Double Contingency Principle,
- Analyze thoroughly, completely, and comprehensively,
- Identify Criticality Safety Limits and Criticality Safety Controls,
- Document in a format consistent with the criteria for technical review, facility implementation, and external audit,
- Conduct the evaluation in a timely and cost-effective manner.

The WSMS methods manual provides guidance on the development of a DCA. This information is presented as a series of steps that should be followed to provide consistency and direction.

The first step is to determine the scope of the effort by specifying the portions of the facility process that will be subject to the analysis. This is often done in conjunction with the second step, selecting team members. Team members should be experienced representatives from Criticality Safety, Facility Operations and Facility Engineering should be present. The availability of multiple facility organizations produces a high quality product that does not unnecessarily restrict the project. In the case of the CSSC project this group of representatives was known as the DCA team, because the end result of the analysis was to be a Double Contingency Analysis. It is important to realize that the DCA team met numerous times and that a considerable amount of time and effort was put into discussing potential credible/incredible scenarios.

Once the scope of the project has been determined and a team assembled, the team members should perform a walk-down of pertinent areas of the facility and/or process and assemble appropriate input information. Since the CSSC facility and process design is approximately 30% complete, a paper walk-down was accomplished by gathering preliminary facility drawings and process information.

The next step is to establish the facility and process boundaries. The process boundaries are further divided into task groupings. Scenarios are defined based on the facility/process boundaries and the task groupings. As the DCA development process proceeds, the team should discuss the activities, potential scenarios and potential controls for each facility/process boundary and task before moving on to the next facility/process boundary of task.

The majority of time expended when conducting a DCA is taken up by the next step, determining potential criticality scenarios. At this point in the project, the ultimate goal of criticality safety is to preclude, through the application of design changes, the possibility of a nuclear criticality accident. To that end, analysts work with the design authority to attempt to modify the process design to design away criticality initiators, thus making the event incredible. In order to make a credible/incredible decision based on engineering judgment, it is necessary to provide a process that can be used for making the necessary engineering judgment.

The Double Contingency Principle (DCP) from ANSI/ANS-8.1 states that process designs should incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality is possible.

The CSSC DCA analysis used the following guidelines, as established in the WSMS Nuclear Criticality Safety Methods Manual, for qualitatively judging the credibility of a potential criticality scenario. It must be emphasized that the guidelines are only intended to bring a measure of consistency and direction to the engineering judgment discussions of the DCA team.

- Four or more independent and unlikely human failures of a robust barrier to criticality
- Three or more independent equipment failures
- Any justifiable combination of the above two guidelines
- A fissile configuration cannot be assembled, due to insufficient mass or less than optimal configurations or due to insufficient “time at risk” for the fissile material involved in the process

There is a strict hierarchy of controls. Passive engineered controls are considered the most reliable, with active engineered controls being the next most robust. Administrative controls are usually considered the least protective, because humans have a higher failure rate than electronics or passive barriers.

After the credible and/or incredible scenarios have been identified it must be determined if the scenario development process identified the need for additional limits or new evaluations. If so, the team must return to assembling appropriate input information and repeat the process.

The team must then identify all the possible controls for each credible criticality scenario. The strength and robustness of considered controls should be assessed. When necessary, DCA team should consider adding temporary members to supplement the knowledge of the team on specific areas, such as fire or NDA. The controls should be outlined with the most robust controls first. The team must then pick at least two independent, unlikely to fail controls for application to double contingency. Controls/barriers identified and implemented in addition to the controls for double contingency are considered defense in depth.

After determining if the scenario or control development process identified the need for additional limits or new evaluations, the NCSE is developed per guidelines contained within DOE-O-420.1B, DOE-STD-3007-2007, and the WSMS Methods Manual. An independent technical and facility review of the NCSE is conducted and comments incorporated. The NCSE is then submitted for final approval and implementation.

4.0 Evaluation and Results

4.1 Summary of Scenarios

Scenarios were developed for TSR normal, TSR restricted, and abnormal operations in the NDA Room, Packaging Area, the Glovebox, Storage Room, and the Ventilation System/Area. Separation between units, total mass, moderation, and reflection are all characteristics of concern. The physical form of the fissile material involved (oxide or metal) is also significant.

The normal TSR mode included scenarios for all of the unit operations areas (NDA room, packaging area, glovebox room, storage room and ventilation system). Not all of the unit operations areas are considered in the Restricted TSR modes. The waste handling restricted mode addresses all unit operations areas except the ventilation system. The restricted modes for 3013s containing plutonium oxide with less than 4% ^{240}Pu and 3013s or Bagless Transfer Cans (BTCs) containing Pu metal consider only the NDA room, packaging area and glovebox room operations. All scenarios applicable to the TSR restricted mode for 3013s containing less than 4% ^{240}Pu scenarios bounded by the scenarios for 3013s or BTCs containing Pu metal because Pu metal is more reactive than Pu oxide.

The scenarios consider criticality accidents caused by a variety of sources. Scenarios considering handling errors that accumulate too many fissile units (interaction) are applicable to all of the unit operations areas except for the ventilation system. The introduction of moderator is applicable to all unit operations areas and can be brought about by several different failures. Moderator could be introduced into any of the operations areas because of a failure of the non-hydrogenous fire suppression system during a fire, violation of multiple administrative controls, or a mechanical failure. Reflection, also applicable to all unit operations areas can be added by placement of units close to concrete or a gathering of personnel around fissile material. One parameter, restricted mostly to the storage area, involves the separation between units and could be affected by an earthquake, or failure of a passive design feature.

Several examples of scenarios include for the normal TSR mode, “A criticality accident caused by introducing too many 3013 containers into the NDA Room outside of qualified positions” and “A criticality accident is caused in the ventilation ductwork caused by the long term accumulation of fissile material.” For the TSR restricted modes scenario examples include “A criticality accident caused by introducing too much plutonium metal into the glovebox,” “A criticality accident caused when a fire involves the waste pail storage array resulting in the introduction of a moderator,” and “A criticality accident caused when too many 3013s are introduced into the Neutron Multiplicity Counter (NMC) cavity.”

4.2 Proposed Controls

The CSSC has made use of passive, active engineered and administrative control features to preclude a criticality event. While passive and active engineered features are taken advantage of, administrative controls make up the bulk of the barriers to criticality.

4.2.1 Passive engineered and active engineered controls

Some of the passive engineered controls include a requirement for the storage racks to be seismically qualified and a passively safe NMC. Requiring the storage racks to be seismically qualified allows the storage racks to maintain spacing between 3013s during a design basis earthquake. Boral plates will also be mounted in a seismically qualified fashion behind the storage racks in the storage room. The NMC in the NDA room will be of a passively safe design to reduce the risk of a criticality accident caused when a fire internal to the NMC causes a 3013 to fail and the fissile contents mixes with the PE of the NMC. All of the unit operations areas (except for the ventilation system) of the CSSC facility will use a Safety Significant non-

hydrogenous fire suppression system as an active engineered barrier to a fire induced criticality. There area also no major sources of moderation in the packaging room, glovebox or ventilation systems/areas.

4.2.2 Technical Safety Requirement Modes

The CSSC will handle fissile units in metallic and oxide form. The subcritical mass limit of plutonium metal and plutonium oxide is significantly different. ANS 8.1 lists the subcritical mass limit for unmoderated plutonium metal as 5.0 kg while plutonium oxide has a subcritical mass limit of 10.2 kg with a maximum of 1.5 weight percent water moderation. Optimally moderated ^{239}Pu , homogeneously mixed in water gives a subcritical mass limit of 0.450 kg. The subcritical mass limits are given for spheres of the material at full theoretical density with full water reflection and are conservative. Because of this difference in the subcritical mass limits, two different modes of handling operation were required when handling metal. The various TSR modes of operation that will be evaluated for criticality accident scenarios are discussed below.

4.2.1.1 Normal Mode: In CSSC outside of the Storage Room storage rack:

a) Up to three 3013s or BTCs with plutonium oxide (no less than 4 wt. % of Pu-240 in the plutonium) and/or uranium oxide (no less than 5 wt. % of U-238 in the uranium), up to 410 g of plutonium as oxide in standards, and up to 150 g of plutonium (and/or uranium) as samples. Five-gallon waste pails in an isolated storage array (e.g., storage cage) may be present in the Packaging Area. Only one 3013 or its contents, plus up to 600 g of plutonium (and/or uranium) as oxide in glovebox residue is allowed in the Glovebox Room. Approximately 2,000 storage positions in the storage rack may be filled with 3013s. Some positions may contain calibration standards and sources. For the TSR Normal Mode, the door to the storage rack(s) containing plutonium metal, plutonium oxide with plutonium containing less than 4 wt. % of Pu-240 or uranium oxide with uranium containing less than 5 wt. % of U-238 is locked and the waste pail isolated storage array is locked.

4.2.1.2 Restricted Modes: In CSSC outside of Storage Room storage rack:

a) One 3013 or BTC with plutonium metal (up to 100% of Pu-239) and/or uranium metal (up to 100% of U-235), up to 410 g of plutonium as oxide in standards, and up to 150 g of plutonium and/or uranium in samples. Five-gallon waste pails in isolated storage array in the Packaging Area. Up to 600 g of plutonium and/or uranium as oxide in glovebox residue.

b) One 3013 with plutonium oxide (less than 4 wt. % of Pu-240 in the plutonium) and/or uranium oxide (less than 5 wt. % of U-238 in the uranium), up to 410 g of plutonium as oxide in standards, and up to 150 g of plutonium and/or uranium in samples. Five-gallon waste pails in isolated storage array in the Packaging Area. Up to 600 g of plutonium and/or uranium in glovebox residue.

c) Standards for annual calibration of NDA instruments, and up to 410 g of plutonium as oxide in check standards. The total Pu-239 and U-235 mass in all seven annual calibration standards plus one check standard is bounded by 4.0 kg of Pu-239 and 8.5 kg of U-235. Five gallon

waste pails in isolated storage array in the Packaging Area. Up to 600 g of plutonium and/or uranium as oxide in glovebox residue.

- d) One 5-gallon waste pail, up to 410 g of plutonium as oxide in standards, and up to 150 g of Pu and/or uranium in samples. Five-gallon waste pails in an isolated storage array in the Packaging Area. Up to 600 g of plutonium and/or uranium as oxide in glovebox residue.

Creating a subset of controls to preclude a criticality event due to the addition of too much plutonium metal in the glovebox, while within the applicable TSR restricted mode, was one of the more challenging control selection processes. Scoping calculations showed that a 4.4 kg piece of bare plutonium metal interacting with 4.4 kg of plutonium metal in a 3013 is subcritical with nominal reflection as would be present in a glovebox. Some arrangements of the two 4.4 kg plutonium metal pieces could not be assured to be subcritical if one of the pieces was contained only in a BTC. A list of the controls that must be violated for a criticality to occur in this situation follows.

- a) Failure of the TSR Restricted Operations Mode which limits the number of 3013s containing plutonium metal in the CSSC project area to one (including plutonium metal in glovebox)
- b) Failure to perform an inspection of the glovebox before introducing fissile material to confirm that no containers or significant piles of fissile material are present. This inspection will be peer verified and must also fail. There must also be a failure to confirm that the glovebox fissile material residue will be 600 g or less.
- c) Failure of the robust inventory control system used for the glovebox (e.g., use of a bar code reader/computer on the Glovebox Room and the 3013 to confirm that the 3013 can be introduced into the glovebox)
- d) Failure to lock out the can cutter after plutonium metal is removed from its containers and to verify that no fissile material except residual plutonium is present in the glovebox before unlocking the can cutter.

Considering all of the above items in combination, a number of independent failures would be required before a criticality accident could occur. In addition, it is not likely that plutonium metal would be introduced as a single solid chunk of alpha phase metal (density of 19.86 g/cc) in the optimum configuration. Given the nature of the process it is likely that the plutonium metal from the first 3013 introduced would have moved to a glovebox workstation where it would not interact with a second plutonium metal 3013 introduced in error. Therefore, the collective engineering judgment of the DCA team concluded that this scenario is not credible.

4.3 Results

The DCA team identified approximately 70 scenarios involving interactions of 3013s of Plutonium Oxide and Plutonium Metal, Sources, Standards, and Waste Pails in multiple configurations in each area of the CSSC facility. The most limiting scenarios involved the presence of Plutonium metal in the glovebox. The upset condition was opening of a second metal

or oxide 3013 container and placing that material on top of the previous metal. From this evaluation, it was concluded that criticality was a credible event in CSSC and that controls would be required to be established to reduce the frequency of the event.

For all the scenarios reviewed, the team was able to identify a sufficient number of controls to justify that the occurrence of a nuclear criticality is not credible. These controls are numerous and consist of a combination of passive and active engineered design requirements and administrative controls. The controls set forth to establish that a criticality scenario is not credible must be in place and followed for the conclusion to be valid. One example of the administrative controls is found in the proposed TSR modes of operation shown in Section 4.2.2.

Although the team was able to justify, with a sufficient number of controls, that a criticality in CSSC is not credible Criticality Accident Alarm System (CAAS) is included in the project scope baseline. The CAAS is included because the facility is intended to handle significant quantities of fissile material, the facility is intended to have a long mission life, the current project design is only about 30% complete, and the controls set contains administrative controls.

5.0 Conclusions

The NCSE evaluates fissionable material operations conducted at the CSSC. It was concluded that there are no credible criticality accident scenarios for these operations and that Nuclear Incident Monitors may not be required. The evaluation is considered to be preliminary since the design of the facility is not complete. Once the facility design and construction are complete the evaluation will have to be reviewed and revised if necessary.

This preliminary NCSE is based on approximately 30% design. The development of the final NCSE is an iterative process that incorporates project changes as the design matures. This preliminary NCSE assumes that the identified controls/control strategies required to conclude that a criticality accident is not credible will be implemented. As a result, NIMs may not be required for the CSSC Project, but are recommended to be included in the facility scope.

As the CSSC design matures, the Nuclear Criticality Safety Evaluation process will continue to evaluate the need for NIMS.

6.0 References:

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